Forum for Electromagnetic Research Methods and Application Technologies (FERMAT)

A Method for Determination of of Planar Transmission Substrates with

Plamen I.

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Abstract

The paper considers the problems of the *substrate dielectric anisotropy* and determination of so-called *equivalent dielectric constant* of different planar transmission lines on anisotropic substrates, when they have been covered with dielectric overlays with open or shielded top surfaces. The idea is to investigate the possibilities for a direct measurement of the equivalent dielectric constant of microstrip lines and coplanar waveguides by covering with thick enough dielectric overlays from the same material. A direct method has been proposed for determination of a set of three equivalent parameters of microwave substrates, applicable for more accurate 3D design of microwave planar structures by electromagnetic simulators.

Index Terms: dielectric substrates, electromagnetic anisotropy, equivalent dielectric constant, planar transmission lines

Equivalent Dielectric Constant Lines on Anisotropic Dielectric Overlay

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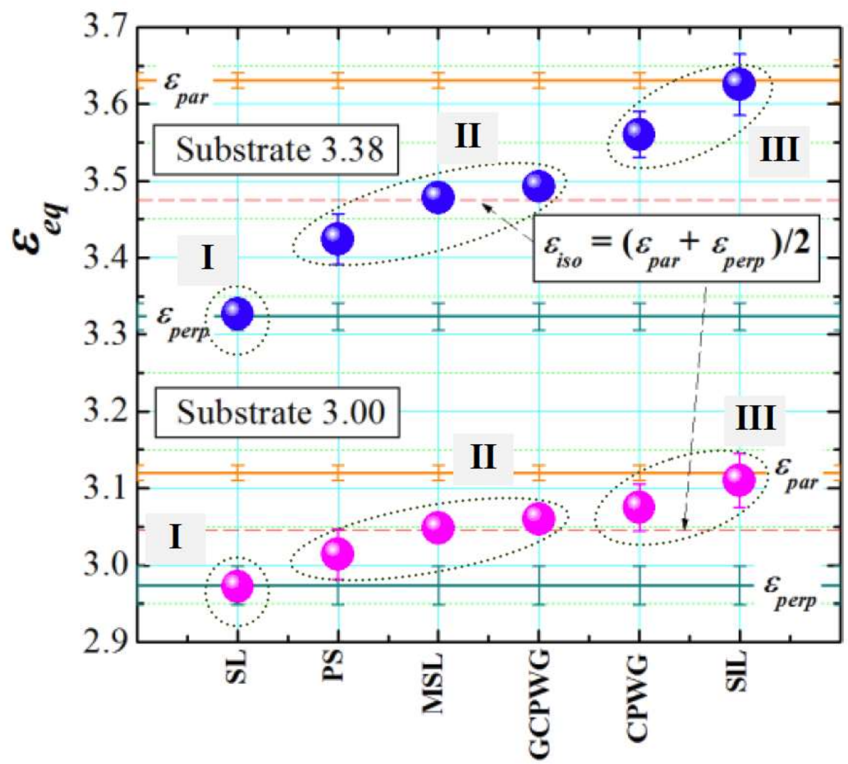
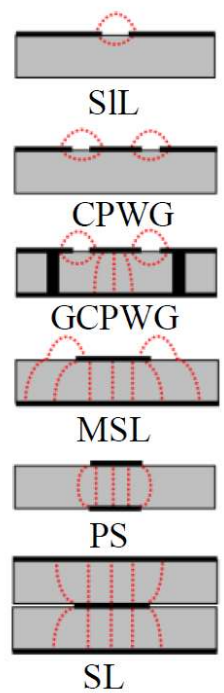
Conclusions

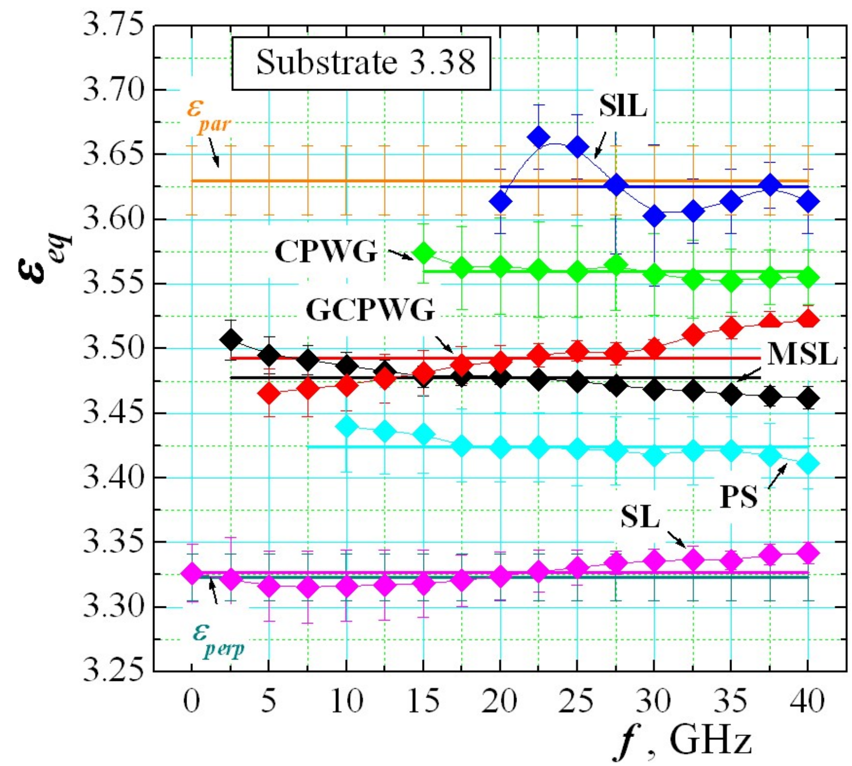
A set of three important equivalent dielectric constants useful for accurate 3-D design of different planar structures on anisotropic substrates – so-called "*stripline*" (or specification) *Dk_SL*, "*microstrip*" (or design) *Dk_MSL* and "*coplanar*" *Dk_CPWG* values can be directly determined by measurements of the effective dielectric constants of covered and shielded microstrip lines (MSL) and coplanar waveguides (CPWG) on anisotropic substrates with enough accuracy. These equivalent parameters could be applied in the electromagnetic simulators for replacement of the real anisotropic substrates with their isotropic equivalents for more accurate 3-D simulations of various planar structures with dominant normal (*Dk_SL*), parallel (*Dk_CPWG*) or mixed (*Dk_MSL*) electric fields.

Dielectric Substrate Anisotropy and Measured Equivalent Dielectric Constant of Different Planar Lines

The modern artificial substrates with microwave and millimeter-wave applications have more or less expressed *dielectric anisotropy*: different dielectric constants (*parallel* $\varepsilon_{\parallel}$ or *perpendicular* $\varepsilon_{\perp}$) in different directions. This anisotropy should be taken into account in the modern 3-D design to achieve better accuracy. One of the possible ways is to *replace* each real anisotropic structure with an isotropic equivalent introducing an *equivalent dielectric constant* ε_{eq}. The big problem is that the different planar transmission lines have *different equivalent parameters* [7] depending on the actual E-field distribution of the dominant mode (see the graphics). How to solve the problem in order to ensure better 3-D design?







Concept for the Equivalent Substrate Parameters, Suitable for Reliable Design Planar Structures by 3-D Electromagnetic Simulators

Three different groups of values for the equivalent dielectric constants could be acceptable for introduction in the modern 3D-design of planar structures:

I) "Microstrip" value: $\varepsilon_{eq} = \varepsilon_{eq\_MSL}$ (or so-called "***design Dk***") for planar lines with mixed distribution of parallel and perpendicular electric fields suitable for: microstrip lines, coupled microstrip lines (for even and odd modes); paired (parallel) strips, grounded coplanar waveguides, and similar planar structures;

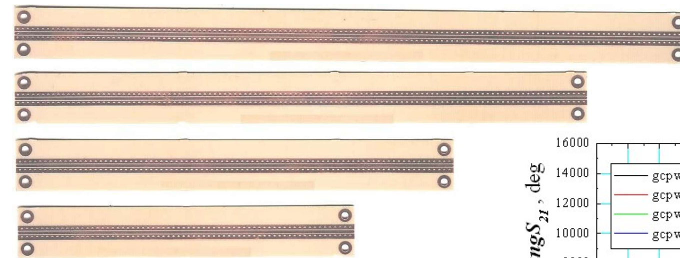
II) "Stripline" value: $\varepsilon_{eq} = \varepsilon_{perp\_sub}$ (reference, process or "***specification Dk***", obtained by the known IPC-TM-650 2.5.5.5 clamped stripline test method) for planar lines with predominant perpendicular electric fields: striplines, substrate integrated waveguides SIW, wide parallel-plate structures and similar planar lines.

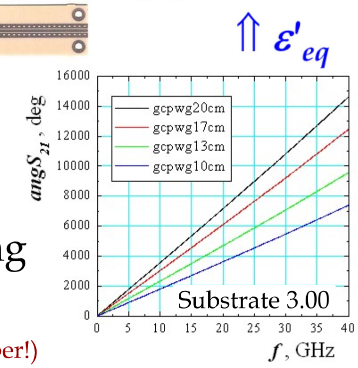
III) "Coplanar" value: $\varepsilon_{eq} = \varepsilon_{eq\_CPWG}$ (a new parameter "***coplanar design Dk***") for planar lines with predominant parallel electric fields: coplanar and slot-based transmission lines, mainly coplanar waveguides, slot lines, fin-lines, etc. (for slot lines the value $\varepsilon_{eq} = \varepsilon_{par\_sub}$ is most suitable);

This is our workable concept for utilization of the equivalent substrate parameters for reliable 3-D design of planar structures on anisotropic substrates.

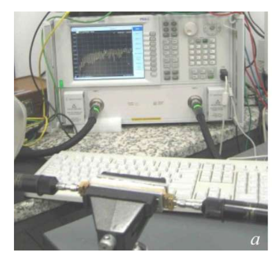
Methods for determination of the *equivalent Dk*

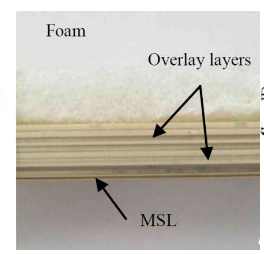
1) Indirect differential phase-length method [7]

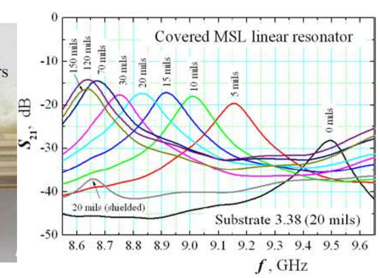




2) Direct measurement using covered/screened planar linear/ring resonators (this paper!)

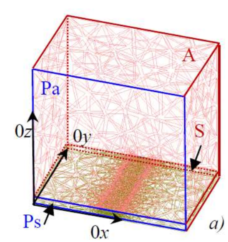


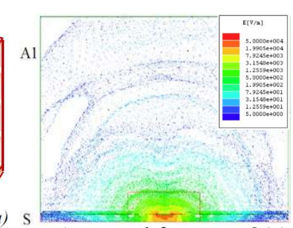




3) Direct calculation using E-field distributions

$$\varepsilon_{eq\,MSL} \cong \left(\left.\frac{E_{par}}{E_{tot}}\right|_{MSL} \times \varepsilon_{par}\big|_{sub} + \left.\frac{E_{perp}}{E_{tot}}\right|_{MSL} \times \varepsilon_{perp}\big|_{sub} \right)$$





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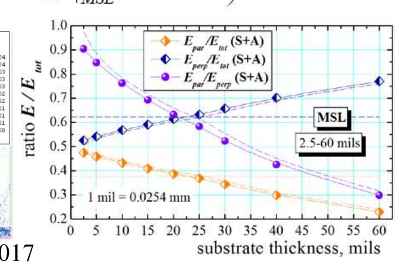


Investigated Covered and Shielded MSL and CPWG Structures

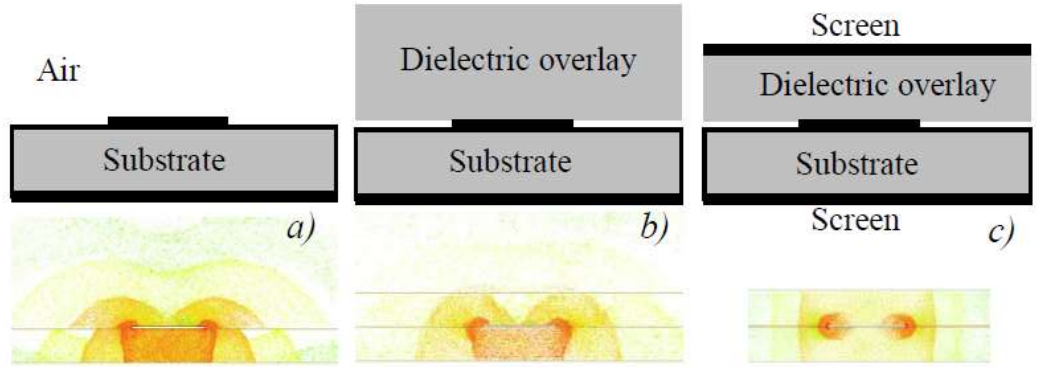


Fig. 2. A set of several microstrip line structures and simulated E-fields: *a*) uncovered MSL; *b*) covered MSL (MSL with dielectric overlay); *c*) screened MSL (considered as a non-50-Ohms stripline SL)

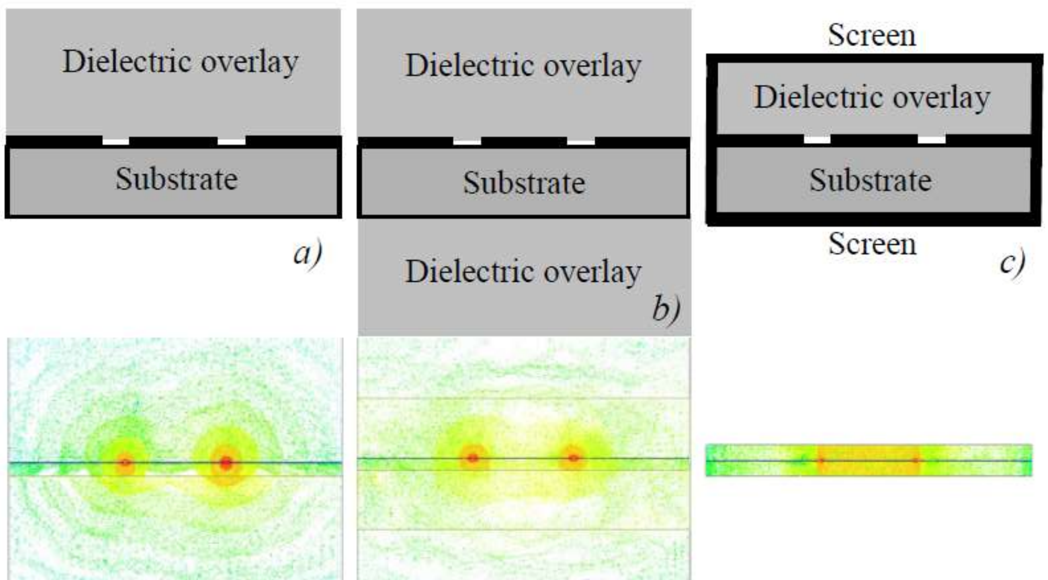


Fig. 3. A set of several coplanar waveguides and simulated E-fields: *a*) covered CPWG on the top surface; *b*) covered CPWG on the both surfaces; *c*) screened CPWG with top, bottom and ensured lateral metallization

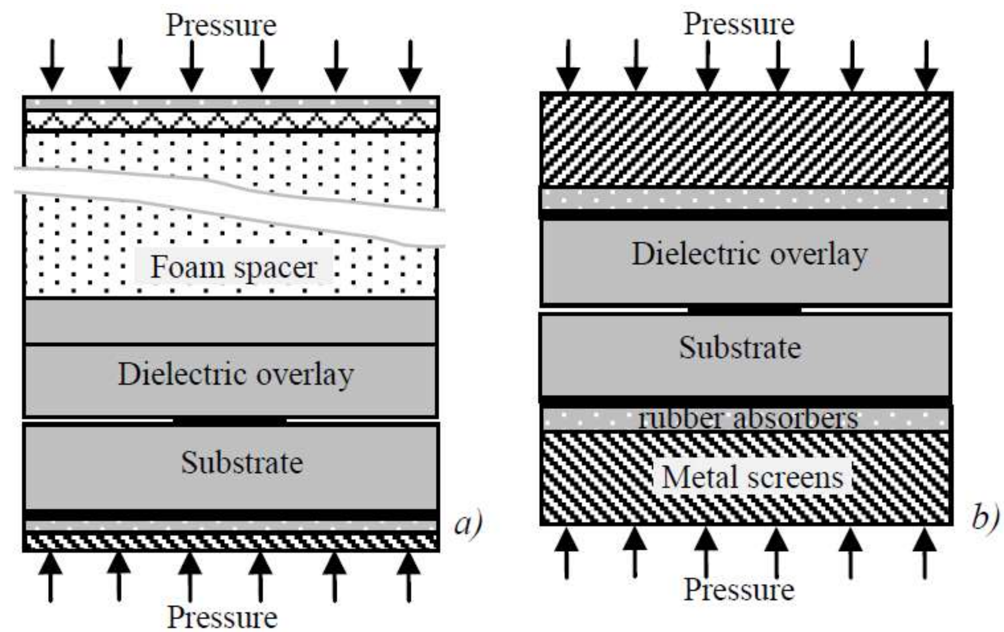
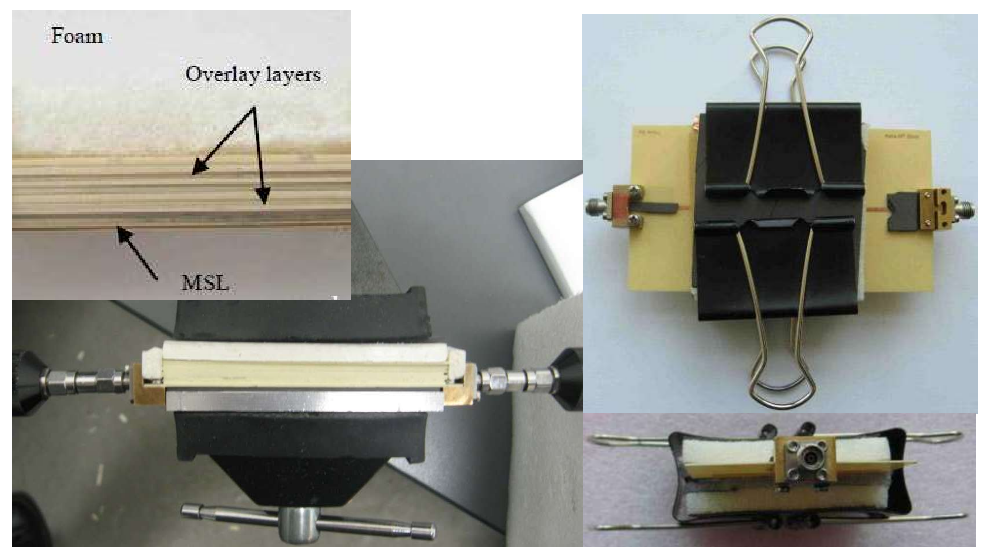


Fig. 4. Schematic view of the covered (*a*) and shielded (screened) (*b*) MSL



Covered and Shielded Microstrip Lines and Air-Gap Influence

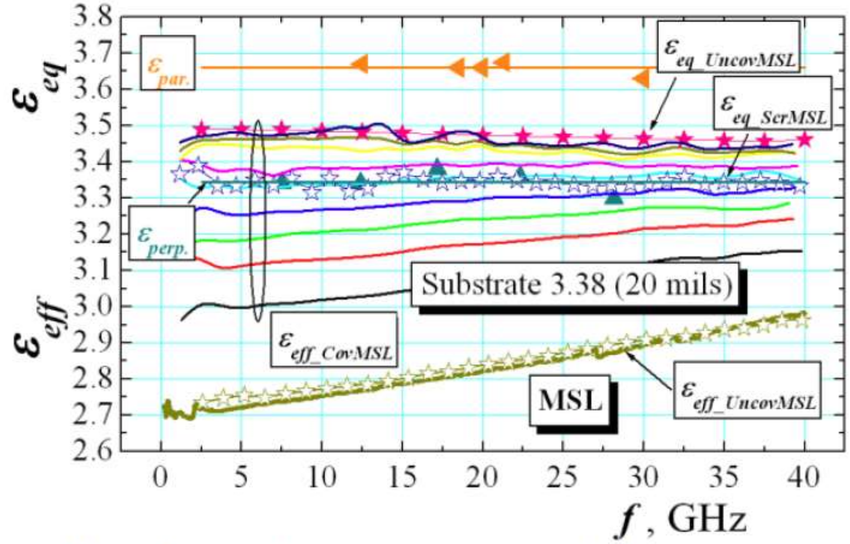


Fig. 7. Measured dependencies of the effective dielectric constant ε_{eff} of uncovered and covered MSL (overlay thicknes from 5 to 150 mils)

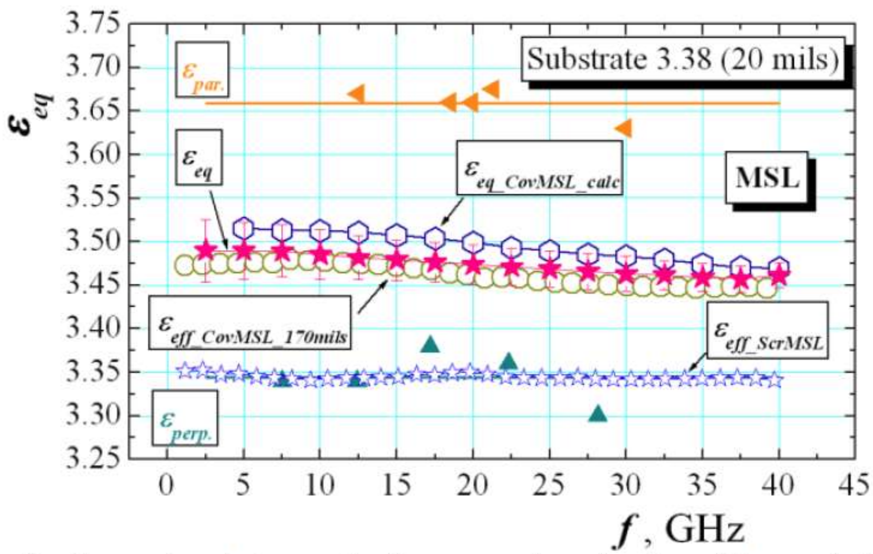


Fig. 8. Comparison between the frequency dependencies of the equivalent dielectric constant ε_{eq} for uncovered and covered MSL, compared with the parallel and perpendicular dielectric constants of the substrate

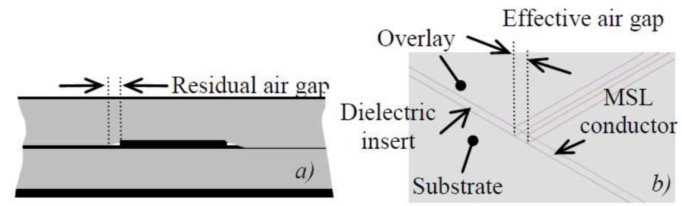


Fig. 9. Illustration of the air gaps, which appear in the covered and shielded planar MSL: *a*) air gaps appear at the edge of the microstrip conductor with finite thickness; *b*) 3D model of an effective rectangular lateral air gap

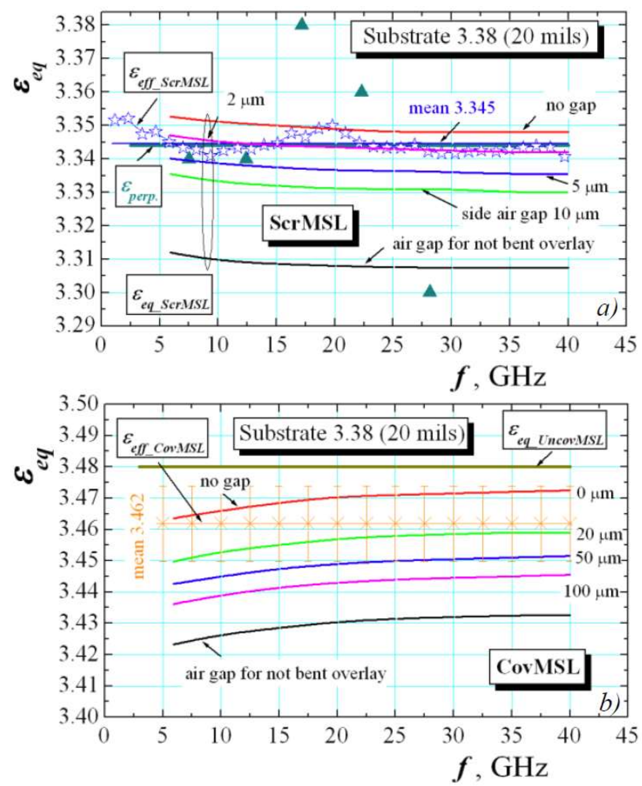


Fig. 10. Measured frequency dependencies of the effective dielectric constant ε_{eff} in *a*) shielded MSL; *b*) covered MSL with 170-mils thick overlay. The measured curves have been compared with numerical curves for structures with different air gaps: air gaps caused by not-bent overlay; without any gap and with lateral gap with different thickness (as in Fig. 9*b*). During the simulations the dielectric constant of the substrate and the overlay is chosen to be: 3.34 for the ScrMSL ($\sim\varepsilon_{perp}$) and 3.48 for the CovMSL ($\sim\varepsilon_{eq\_MSL}$)

Substrates with different thickness

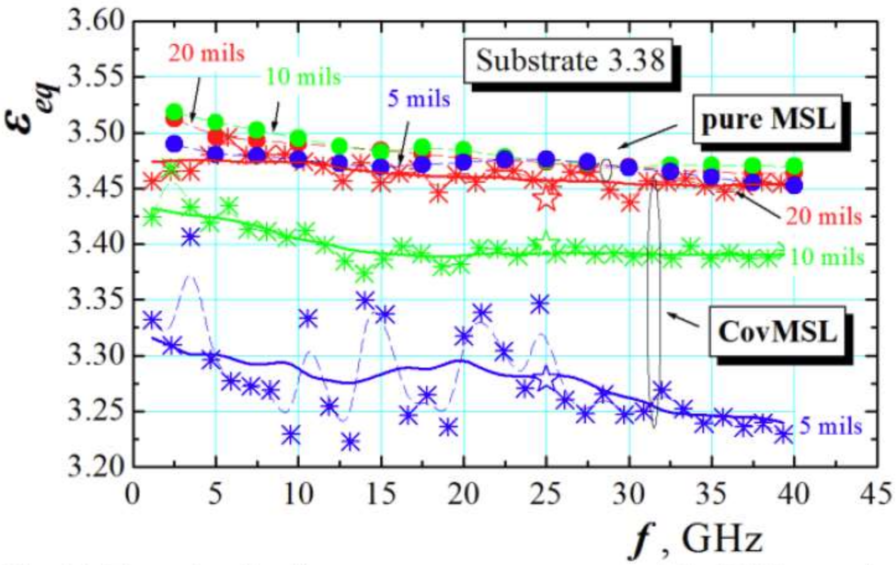


Fig. 11. Examples for direct ε_{eq_MSL} measurements of CovMSL on anisotropic substrate with different substrate thicknes h and overlay thickness $10h$.

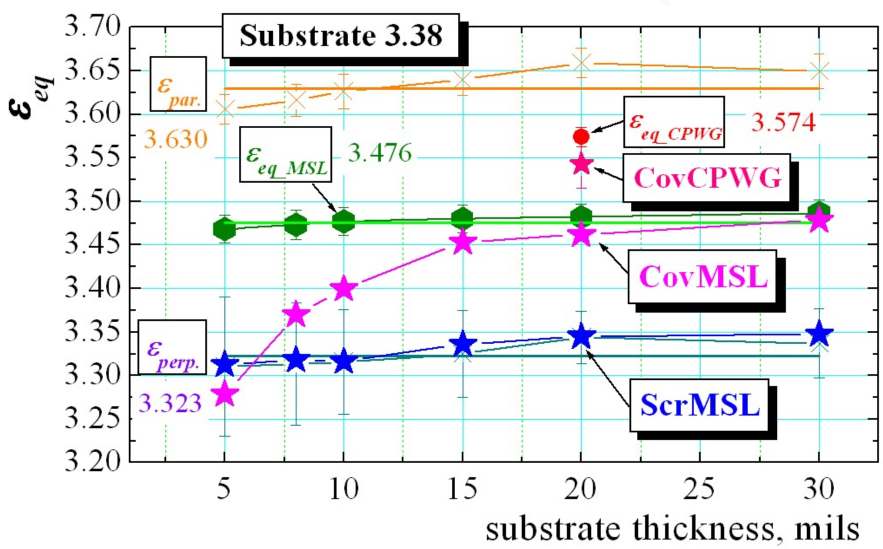
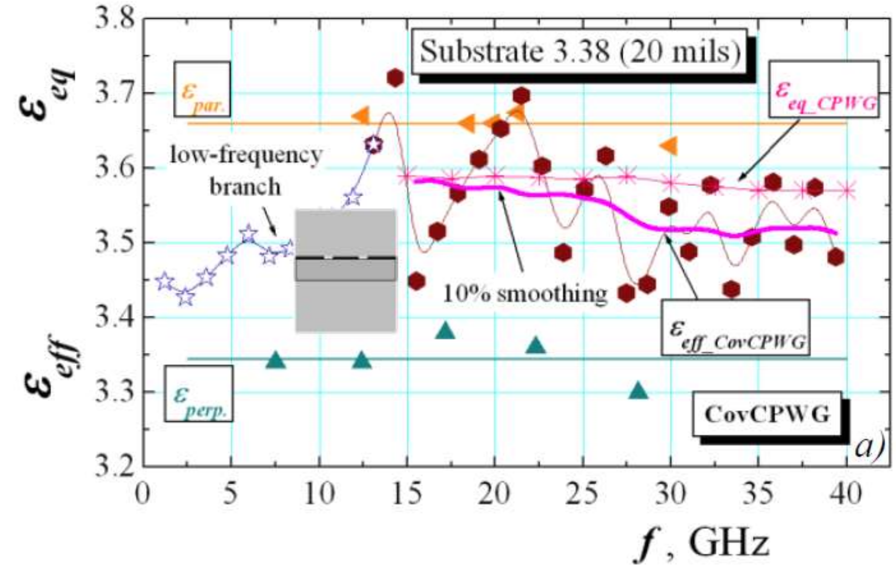


Fig. 12. Measured averaged values of ε_{eq_MSL} (in the interval 5-40 GHz) for MSL, compared with the parallel and perpendicular dielectric constants of one typical substrate with specification dielectric constant 3.38

Covered and Shielded CPWG



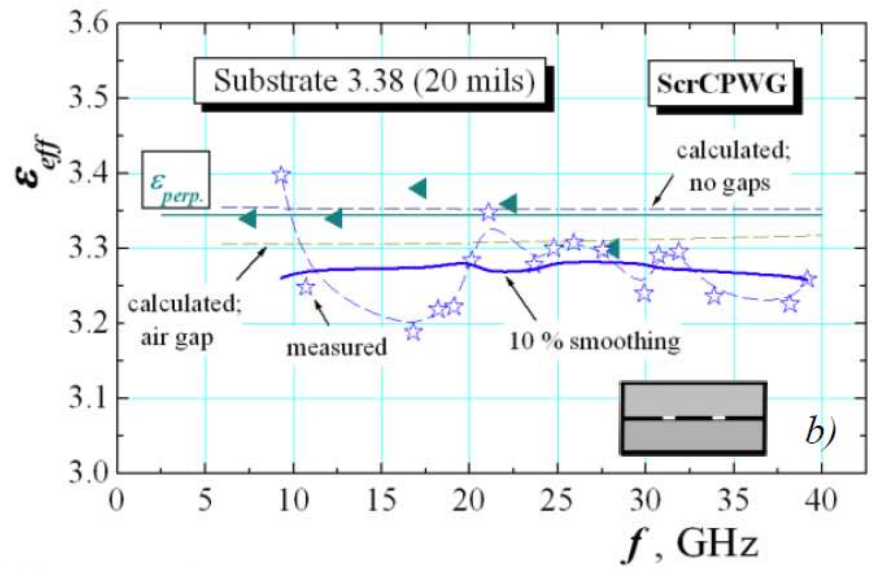
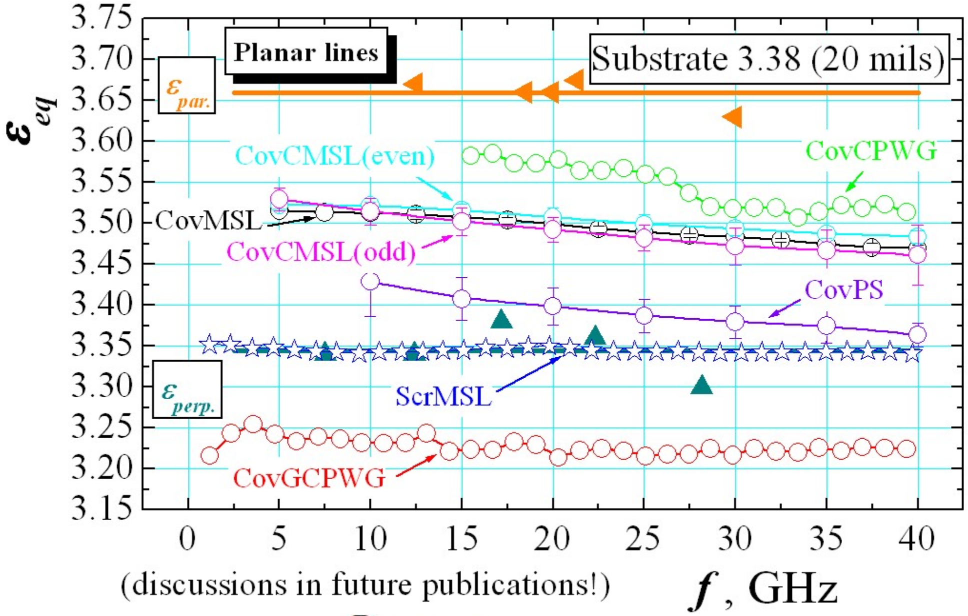


Fig. 13. An attempt for direct measurements: a) of $\varepsilon_{eff\_CovCPWG}$ of CovCPWG (compared with ε_{eq_CPWG}); b) of $\varepsilon_{eff\_ScrCPWG}$ of ScrCPWG (compared with ε_{perp})

Results for Different Covered and Shielded (Screened) Planar Lines



(discussions in future publications!)

REFERENCES

[1] J. Browne, "Weighting the Options for RF/MW Circuits Materials", Microwaves&RF, Lieders in Microwaves, Dec. 2015, pp. 52-54.

[2] R. Sturdivant, "Microwave and Millimeter-Wave Electronic Packaging", Artech House, ISBN 978-1-60807-697-0, 2014, Ch. 2

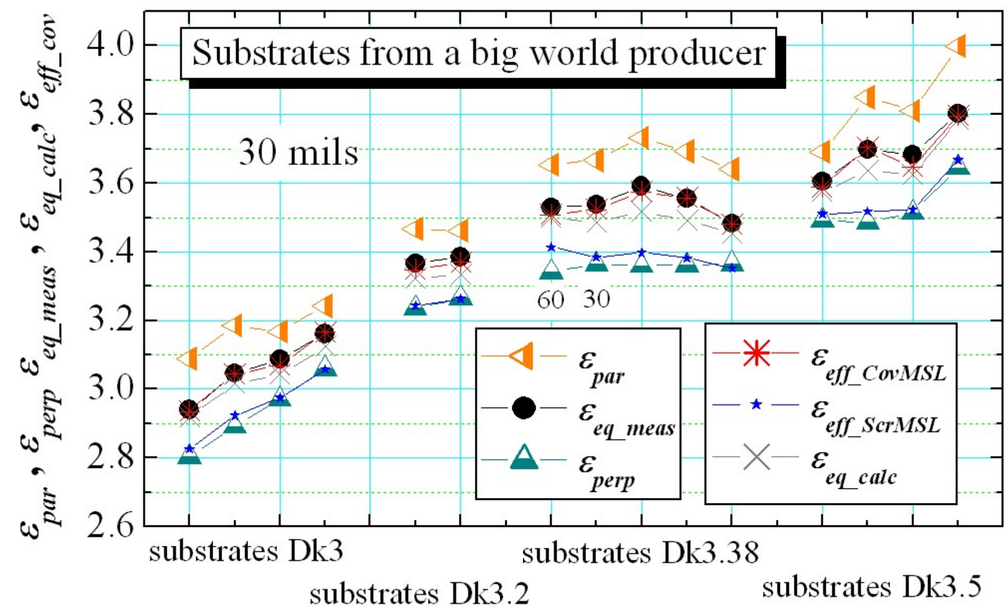
[3] J. C. Rautio, "Shortening the Design Cycle," IEEE Microwave Magazine., vol. 9, no. 6, pp. 86–96, Dec. 2008

[4] P. I. Dankov, "Dielectric Anisotropy of Modern Microwave Substrates", Chapter 4 in "Microwave and Millimeter Wave Technologies from Photonic Bandgap Devices to Antenna and Applications", ed. by Igor Minin, In-Tech Publ., Austria, Jan. 2010, ISBN 978-953-7619-66-4

[5] P. I. Dankov, "Two-Resonator Method for Measurement of Dielectric Anisotropy in Multi-Layer Samples", IEEE Trans. on MTT, vol. 54, April 2006, pp. 1534-1544

[6] V. Levcheva, B. Hadjistamov, P. Dankov, "Two-Resonator Method for Characterization of Dielectric Substrate Anisotropy", Bulg. J. Phys. 35 (2008) pp. 33-52

Comparative Experimental Data for Some Commercial Substrates



[7] Plamen Dankov, "Concept for Equivalent Dielectric Constant of Planar Transmission Lines on Anisotropic Substrates", 46th EuMC, London, UK, October 2016, pp. 158-161

[8] Online: www.rogerscorp.com; http://www.syst.com.cn/en/index.html www.isola-group.com;

[9] N. K. Das, S. M. Voda, and D. M. Pozar, "Two Methods for Measurement of Substrate Dielectric Substrates", IEEE Trans. on MTT, vol. 35, July 1987, pp. 636-642

[10] Keysight Technologies "Split Post Dielectric Resonators for Dielectric Measurements of Substrates, Application notes, http://literature.cdn.keysight.com/litweb/pdf/5989-5384EN.pdf

Plamen I. Dankov is Assoc. Professor in Faculty of Physics, Sofia University, Bulgaria and material characterization consultant of many companies. His education activities are in the area of microwave and wireless technique, measurements, antennas, aerospace engineering. His research interests include microwave gyrotropic devices, microwave material characterization, antennas, EMC problems, microwave measurements, 3D electromagnetic simulations, small satellites. He has more than 100 scientific and popular publications in these areas. Dr. P. Dankov is IEEE Member in 4 Societies: MTT, A&P, I&M, Aerospace. He was member of GA of EuMA and Group 8 representative (2013-2016). He is POC of UNISEC Global in Japan and Secretary of UNISEC Bulgaria.